

A Modular Approach to Model Oscillating Control Surfaces using Navier-Stokes Equations

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Introduction

The use of active controls for rotorcraft [1] is becoming more important for modern aerospace configurations. Efforts to reduce the vibrations of helicopter blades with use of active-controls are in progress [2]. Modeling oscillating control surfaces using the linear aerodynamics theory is well established. However, higher-fidelity methods are needed to account for nonlinear effects, such as those that occur in transonic flow [3]. The aeroelastic responses of a wing with an oscillating control surface, computed using the transonic small perturbation (TSP) theory, have been shown to cause important transonic flow effects [4] such as a reversal of control surface effectiveness that occurs as the shock wave crosses the hinge line. In order to account for flow complexities such as blade-vortex interactions of rotor blades [5] higher-fidelity methods based on the Navier-Stokes equations are used.

Reference 6 presents a procedure that uses the Navier-Stokes equations with moving-sheared grids and demonstrates up to 8 degrees of control-surface amplitude, using a single grid. Later, this procedure was extended to accommodate larger amplitudes, based on sliding grid zones [7]. The sheared grid method implemented in Euler/Navier-Stokes-based aeroelastic code ENSAERO [6] was successfully applied to active control design by industry [8].

Recently there are several papers [9, 10, 11, 12] that present results for oscillating control surface using Reynolds Averaged Navier-Stokes (RANS) equations. References 9 and 10 report 2-D cases by filling gaps with overset grids. Reference 9 compares integrated forces with the experiment at low oscillating frequencies whereas Ref. 10 reports parametric studies but with no validation. Reference 11 reports results for a 3D case by modeling the gap region with a deformed grid and compares force results with the experiment only at the mid-span of flap. In Ref. 11 grid is deformed to match the control surface deflections at the section where the measurements are made. However, there is no indication in Ref. 11 that the gaps are explicitly modeled as in Ref. 6. Computations using overset grids are reported in Ref. 12 for a case by adding moving control surface to an existing blade but with no validation either with an experiment or another computation.

In Ref. 13 an oscillating control surface was simulated in RANS based OVERFLOW code [14] using overset grids in gaps and was validated with experiment for integrated air loads. Ref. 13 reports significant differences between computations and measurements, particularly for flap moments. While the approach presented in Ref. 13 promises to be accurate, a promise that has yet to be realized in such quantities as unsteady surface pressures, it also requires more grid points and a more complicated grid generation process. Time step restrictions associated with tightly spaced grid points in gaps can also be an issue with this approach.

As an alternate approach to the method of modeling gaps with overset grids [13], the present work presents a sheared grid capability [6] embedded as a module into the overset grid based OVERFLOW code. The shearing grid approach has been successfully implemented in patched grid as demonstrated in Fig. 1 taken from Ref. 15. In this approach the grid at the flap's gap for the deflected control surface has the same topology as the grid for un-deflected control surface. Control surface deflections are modeled by shearing the grid at the gap. Sheared grids produce accurate results for moving control surfaces [6, 15] and can be numerically more efficient than methods that use overset grids to model small gaps, which are common when active control surfaces are used.